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Expert Systems are computer programs that draw upon a human generated knowledge base and problem solving strategy to allow non-experts to act like experts. While that definition may not be widely accepted, the technology behind it is becoming widely accepted.
Not many years ago, Expert Systems were almost exclusively developed on specialized expensive machines by specialists called knowledge engineers. These early applications were typically expensive, not particularly user friendly, and often designed to demonstrate what the technology might do rater than to cost effectively solve a problem. Today, however it appears that highly useful Expert Systems are being developed in relatively large numbers on inexpensive Personal Computers (PC's) by scientific, engineering, and technical personnel who do not have specialized Expert Systems training. What has brought about this dramatic changes in direction?
This paper describes the changes in hardware and software tools that have aided and permitted this most beneficial change and their acceptance by a wide variety of users. Included in this discussion is by a*

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Implications for the future are lastly discussed in light of these recent trends, and estimates are made regarding the types and frequency of likely future applications.

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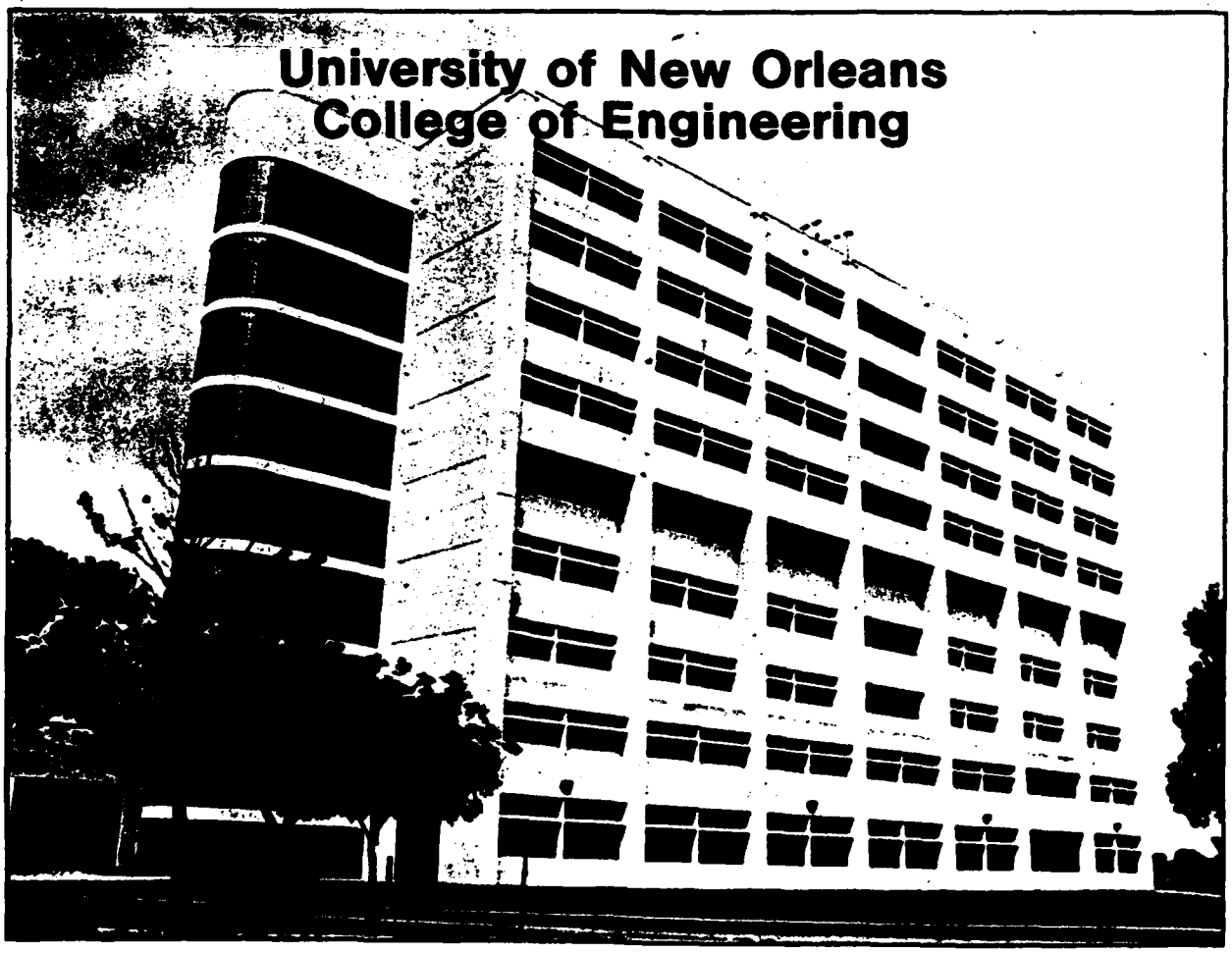

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Trends In Expert Systems

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Abstract:

Expert Systems are computer programs that draw upon a human generated knowledge base and problem solving strategy to allow non-experts to act like experts. While that definition may not be widely accepted, the technology behind it is becoming widely accepted.

Not many years ago, Expert Systems were almost exclusively developed on specialized expensive machines by specialists called knowledge engineers. These early applications were typically expensive, not particularly user friendly, and often designed to demonstrate what the technology might do rather than to cost effectively solve a problem.

Today, however, it appears that highly useful Expert Systems are being developed in relatively large numbers on inexpensive Personal Computers (PC's) by scientific, engineering, and technical personnel who do not have specialized Expert Systems training. What has brought about this dramatic change in direction?

This paper describes the changes in hardware and software tools that have aided and permitted this most beneficial change and their acceptance by a wide variety of users. Included in this discussion is a description of the changes that have also taken place in the kinds of applications being pursued and the results they are bringing in the area of productivity.

Implications for the future are lastly discussed in light of these recent trends, and estimates are made regarding the types and frequency of likely future applications.

1.0. THE EXPERT SYSTEM REVOLUTION

From the earliest days of electronic computation, people have sought ways to give computers human-like intelligence. It seemed intuitively obvious that a machine that could calculate and/or perform logical operations at such lightning speeds would be an extremely valuable tool in problem solving and the control of complex processes. To some, computers have seemed the perfect extension of human capabilities. Computers don't forget, they can process and compare many more items than humans, they calculate thousands of times faster, and they work on tirelessly. With such wonderful attributes, computers were sure to be the "genie in a bottle" for which we were searching. All that seemed necessary to receive this marvellous gift was to teach computers how to think and reason like people.

2.0. EARLY FAILURES AND SUCCESSES

Unfortunately, people, even those viewed by others as not very smart, have ways of accessing, processing, and utilizing information (note I did not say data) that appear natural, comfortable, and extremely difficult to figure out. It seems that in our quest for understanding and control of the world in which we live, that we understand ourselves least. Early efforts at creating intelligent computers centered around decision making, specifically logical decision making. Was something too hot (or cold), too fast (or slow), should it be on or off, or any one of a thousand different yes or no type decisions. This is low level intelligence of a sort, but itwas soon realized that the computer was merely parroting a decision tree that first had to be structured in its entirety and completeness by a human being! Such experiences lead to attempts to define intelligent behavior; resulting in more or less general agreement that intelligent behavior results when, in the course of interacting with the unit through some communications channel, one cannot tell if there is a human or machine on the other end.

The quest has recently been to develop techniques which, in the final result at least, mimic the reasoning and decision making processes of humans when dealing with information. It was at first thought that totally new computer languages where required to deal with qualitative (non-numeric) items; and in some cases LISP or PROLOGUE is extremely beneficial. But, in the majority of cases much more popular languages will serve just as well or better if thoughtfully applied. In fact, the computer language of choice is rapidly becoming "C"; not because it is a good Expert System's language, but because it guarantees portability to a wide variety of computer platforms.

Early attempts at building information processing expert systems utilized special languages (usually LISP) and, often, specialized computer hardware. These early attempts were typically expensive, not particularly user friendly, and often more interested in demonstrating what the new technology might do rather than to cost effectively solve a real world problem. Most of these early efforts are unknown and all but forgotten by their creators. They did, however, provide a foundation upon which the present and rather successful expert systems technology could be constructed. Perhaps what these early efforts did more than anything else was to begin to give us a better appreciation of how effective we humans are at reasoning and idea processing.

One aspect of Expert Systems that probably wasn't recognized initially is their use by an individual as opposed to a group. Expert Systems usually aid a person in analyzing a situation and reaching a conclusion. As such this aid must be readily accessible by an individual(s). The development of relatively high performance, low cost, personal computers (PCs) has, as much as any other advance, enabled the application of Expert Systems techniques on an individual basis. As long as Expert Systems were resident on mainframe or special purpose computers, access was effectively limited to those few who possessed special knowledge and/or special access. While Expert Systems can function in this environment, the types and variety of problems are much more limited than what can be accomplished in a PC situation.

3.0. A MATURING TECHNOLOGY

Over the last few years, Expert Systems concepts and techniques have proven their value in providing affordable solutions to problems dealing with information processing. We have seen a significant change in viewpoint regarding their utilization. Not many years ago, Expert Systems were almost exclusively developed on specialized expensive machines by specialists called knowledge engineers. Today, highly useful Expert Systems are being developed in relatively large numbers on inexpensive PCs by scientific, engineering, and technical personnel who do not have specialized Expert Systems or computer training. What has been responsible for this dramatic change? I think there are 3 major forces at work.

First, as we learned more about how to simulate human reasoning processes certain patterns emerged which gave indication that problems could be grouped into classes. Further, each class of problems could be solved by an Expert System having the appropriate inference engine and applicable knowledge base. Remember that the inference engine is nothing more than the procedure by which knowledge in the knowledge base is applied to the information at hand to solve the particular problem under consideration. With the appropriate inference engine, a whole class of problems could be solved by just altering the knowledge base to match the specific problem under consideration. This generalized problem solving ability using Expert Systems techniques has permitted the development of "shells" which can be purchased to run on PCs and provide users a framework within which problems can be solved expertly. In those problem areas where large numbers of potential users exist, very capable, user friendly shells can and have been created.

Second, the shells and the development tools which surround them have matured significantly in terms of usability. These Expert Systems development tools are typically menu driven (read and follow the instructions), can often extract "rules" from examples only, do syntax and semantic checking, perform debugging, and provide facilities for easily constructing explanations. These tools have for the most part eliminated the need for a specialized knowledge engineer who manually constructs a knowledge base and its IF-THEN rules or frames through interviews with subject matter experts; and then builds an inference engine to effectively apply this knowledge to achieve problem solution.

Third, the amazing evolution of relatively high performance PCs at very affordable prices has provided Expert Systems work platforms which are portable, capable, reliable, and very cost-effective. Without this development, Expert Systems techniques would likely still be limited to large fixed computer installations, operated by specially trained personnel.

The combination, then, of an inexpensive personal computer, inexpensive Expert System shell/development system, and a human with fundamental knowledge of how a particular problem, belonging to a class of problems, should be solved provides all the key ingredients for creating an Expert Systems solution. If the problem requires expertise of limited or costly availability that is needed fairly often, its solution will probably also be more than worth the time and effort to provide it.

4.0 POSSIBILITIES FOR TODAY

So, just what is possible with today's techniques and technology? Table 1 gives a breakdown of the range in capabilities and typical cost of Expert Systems development tools available today. This Table is but a small sampling of what is available in the market place and has been constructed to give an idea of the spectrum of available products. While the present market place certainly provides a wide variety of potential solutions, one is also faced with an almost bewildering choice of products. What procedure can be used to sort through this maze of technology?

In the work we do in applying Expert Systems techniques, our goal is to find an acceptable solution as quickly as possible. An acceptable solution is one which meets the stated requirements for

Product	KNOWLEDGE REPRESENTATION	INFERENCE CONTROL	META - STRATEGIES	USER INTERFACE	DEVELOPMENT AIDS	TYPICAL COSTS
ART (Automatic Reasoning Tool)	Objects, frames, viewpoints, logic, Blackboards	IF/THEN rules, forward, backward, and mixed chaining, inheritance	User-controlled prioritized goals and subgoals	English like language, icons, menus, and windows	Structure or text entry for objects, browsing, tracing, breakpointing	$65,000
Expert Edge	Objects, Attributes, Values	IF/THEN rules, backward and limited forward chaining	Bayesian Statistics	Menus, windows, color capability	Natural language text, automatic conflict checking	$1,500
Intelligence Compiler	Object frames with multiple inheritance	Rule based forward, backward, and mixed chaining	—	Menu-based with graphical displays	Rule manager, built in relational db, Wordstar like editor	$480 (PC) $7,900 (VAX station)
LEVEL 5	Numeric, string, facts, object-attribute slots, facts	IF/THEN rules, forward and backward chaining, and "what if"	Goal selection metaphor	Menus, pop-ups, window function keys, save and restart	Natural language editor, tree reporter, custom screens	$995 (PC) $8,900 (VAX)
NEXPERT Object	Objects with inheritance	Opportunistic, non-monotonic	Procedural Attachments (Demons)	Graphical, mouse-oriented, windows, pop-up menus	Forms, AI Library, AI server, images, datareaders	$6000 (PC) $8,000 (Workstation) $25,000 (Mainframe)
Rulemaster	Scoped variables, abstract data types, user defined operators	IF/THEN rules, forward and backward chaining, induced rules.	Hierarchy of modules	English like language	Pop-ups, knowledge base editor, Turbo C compiler	$795 (PC) $3,900 (Workstation) $7,900 (VAX)
VAX Decision Expert	IF/THEN rules, decision trees, AND/OR trees	Forward chaining and goal-directed reasoning	Probability and cost of search/ priorities of search	Menu driven	Utility language	$8,500

Table 1. Typical range of expert systems development tools

accuracy, completeness, and speed of response; it rarely needs to be the optimum solution. Since time costs money, we also seek to minimize the time spent in finding an acceptable solution. Our approach to tool selection, assuming we don't already have a tool that will provide a solution, is to quickly determine which of the choices might have the features we need at reasonable cost. We look for proof that the tool has been applied to our class of problem with good success; that the tool is complete and probably relatively easy to use; that the tool readily supports interfaces to programs written in other languages; and that compiled run-time programs will probably fit on the target computer.

It is not always easy to determine accurate answers to all these considerations; but you will typically find that the range of choices quickly narrows to a few possibilities. Clearly, in todays computer tools market the programming language "C" is the language of choice because of portability and the run-time size of compiled versions.

There are, of course, the major investment tools which cost $25,000 to $65,000. These tools are very comprehensive and typically come with a lot of technical support from the supplier. They also typically require a large time investment in mastering their spectrum of functions and capabilities. In our experience, they are most useful in situations where large and complex Expert Systems are being developed by specialists and/or where a large number of medium to large systems are being continuously developed. In such development environments (large size/large numbers) the significant cost of these expensive tools can be amortized over many delivered systems.

Table 2 summarizes the manpower time, target computer technology, and tool costs needed for the range of Expert Systems that are being developed today. The range of Expert Systems is categorized by the size of the rule, object, or frame set. While computer execution speeds have increased dramatically over the last four years, it is still wise to keep the total number of "rules" under a couple of thousand. Expert Systems very much larger than 2000 rules often run very slow and can be difficult to validate because of the large number of "what ifs" that must be considered. If faced with a large system, look hard at breaking it up into a number of smaller systems perhaps hierarchically related.

5.0 POSSIBILITIES FOR TOMORROW

As further experience is gained in the application of Expert Systems techniques to problem solving, we should see still greater refinement in features and usability of development tools. Tools will likely become more optimized for each class of problem and we should see marketing efforts which emphasize this optimization. The refined tools will also help users better define problem boundaries and reduce catastrophic or so-called hard failures when problem knowledge goes just beyond those boundaries.

Will we soon see Expert Systems that learn from experience? I seriously doubt it. While much work is ongoing in evolutionary programming and neural nets, we still don't have much knowledge regarding how humans actually learn from experience. We are not very sure how we separate the pieces of the experience and categorize and interrelate them much less provide for selective recall for later infusion into similar but new situations. Neural nets are much the rage these days because they seem to permit limited "learning from experience" for certain problem classes. I suspect that while they are good for recognizing shapes and structure and patterns, we will find that where intellectual inferences are required that they will fail to provide the necessary intelligent usefulness until we grow to understand our own problem solving capabilities much better.

	TYPICAL DEVELOPMENT TIME (MONTHS)	MAN-POWER REQUIREMENTS (FULL TIME)	TYPICAL SYSTEM SIZE (NO. RULES, OBJECTS, FRAMES)	TYPICAL OPERATING ENVIRONMENT	TYPICAL TOOL COSTS
Small Systems	3 - 6	1 - 2	25 - 75	IBM-PC, XT DOS 2.0 up	$500 to $2,500
Medium Systems	12 - 24	2 - 3	150 - 500	IBM-PC-AT DOS 2.0 up	$1,500 to $6,500
Large Systems	24 - 48	3 - 5	1K - 2K	IBM-PC-AT or MicroVAX	$4,000 to $25,000
Very Large Systems	60 & up	5 - 8	3K & up	Sun, Apollo Workstations VAX minis	$8,000 to $65,000

Table 2. Summary of development efforts and cost for expert systems.

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